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Optimization of laser-produced plasma towards the generation of high-order harmonics

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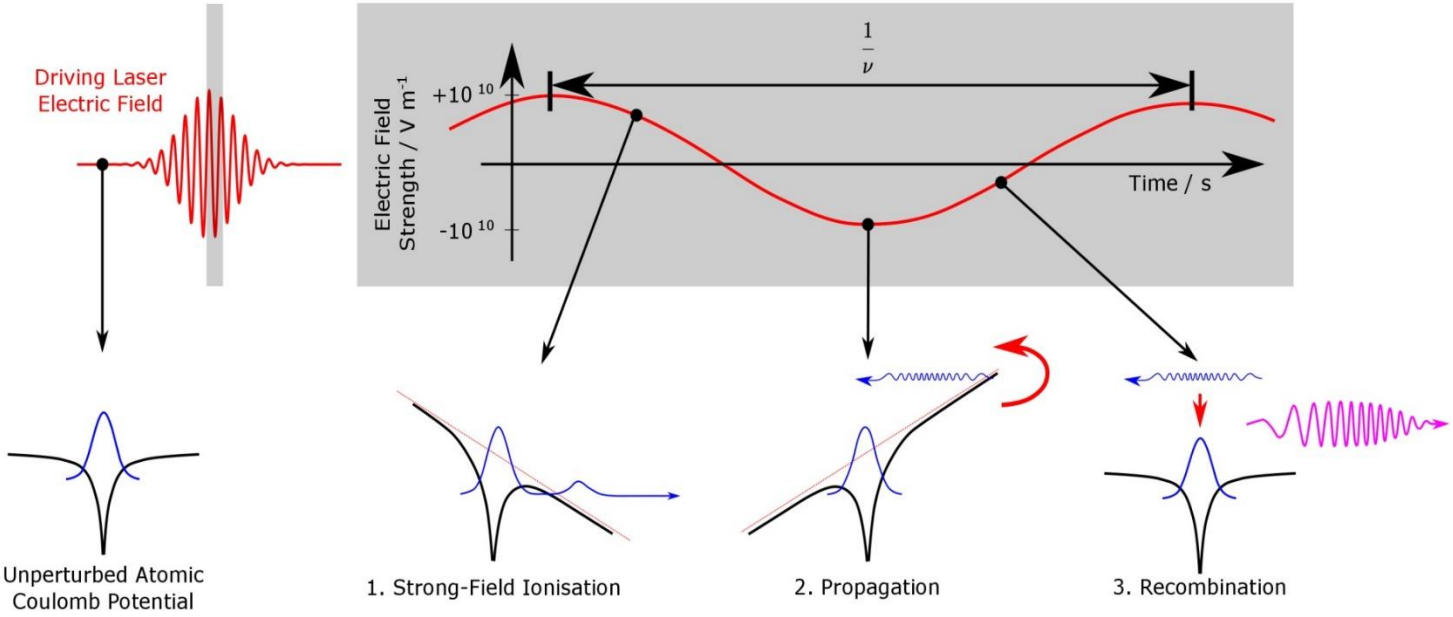
Outline

- **Motivation**
- **High-order Harmonic Generation**
- **Laser Produced Plasmas for HHG**
- **Results**
- **Conclusion**
- **Future plans**

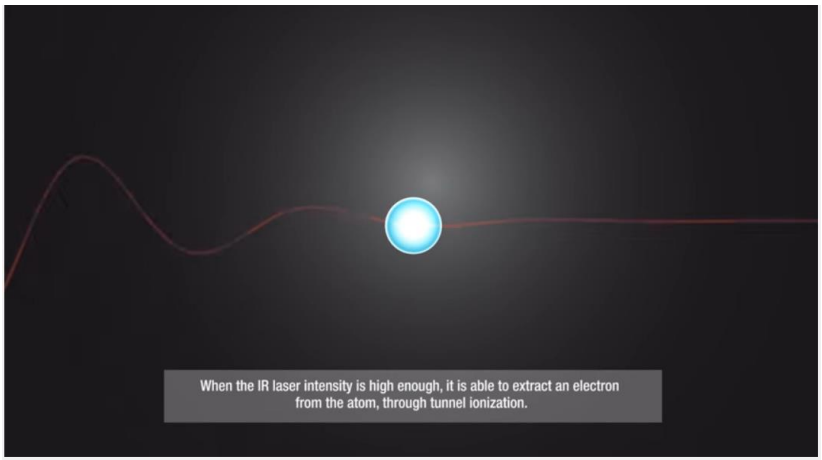
Motivation

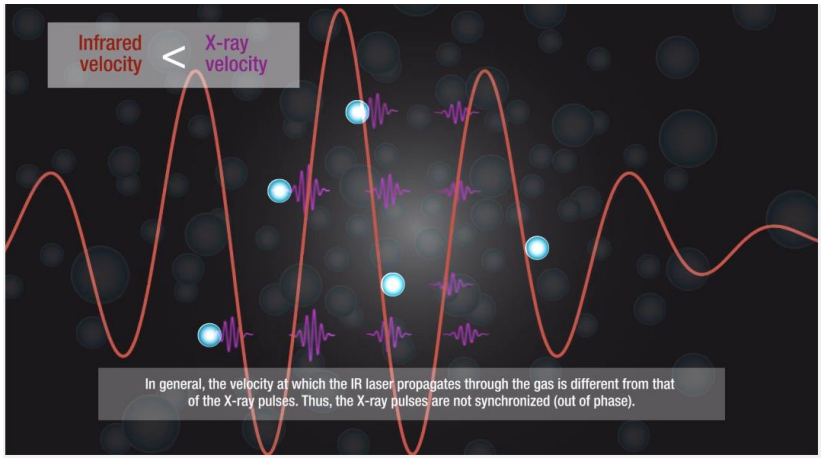
- Increase the energy cut-off of HHG
- Bright laser-like XUV/X-ray beam generation.
- Adding energy tunability XUV/X-ray sources

High–order Harmonic Generation (HHG)



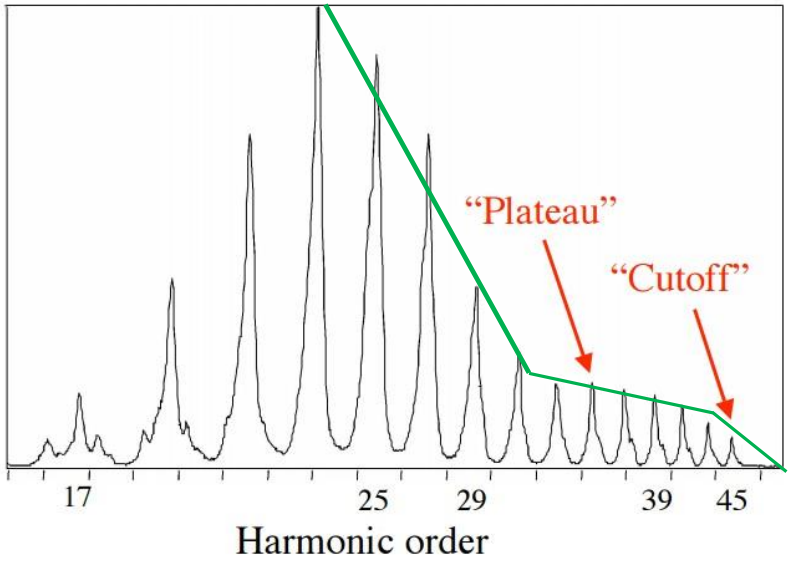
https://www.helmholtz-berlin.de/forschung/oe/em/materialentwicklung/instrumentation/hhg_en.html

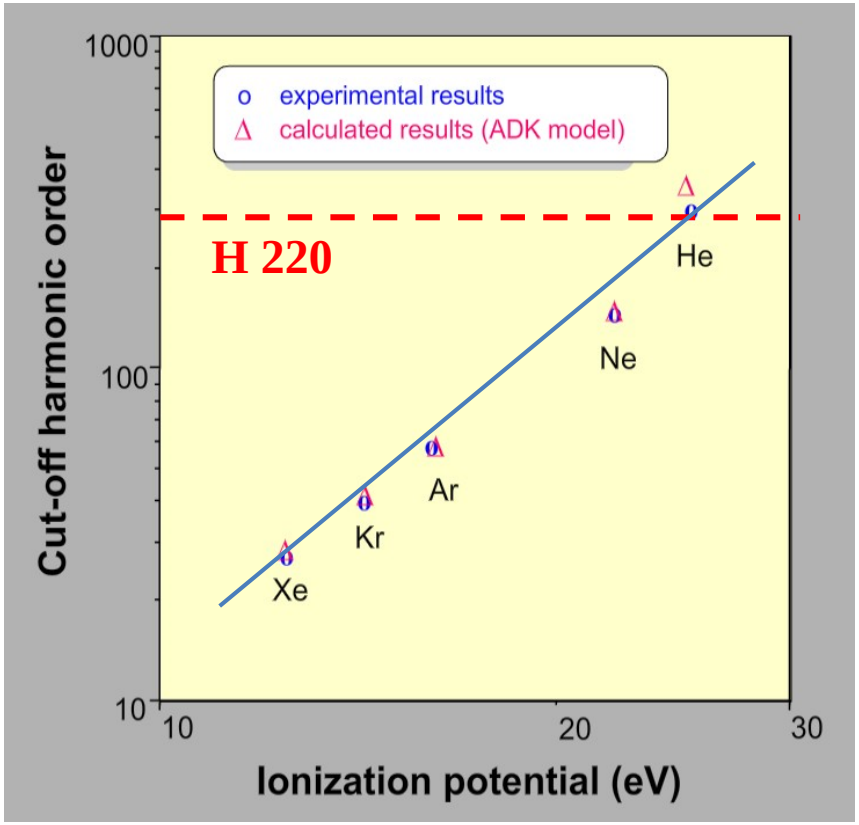




Courtesy: Photonics and Laser Applications Group of University of Salamanca, and JILA, University of Colorado

Typical HHG spectrum





$$E_{Cutoff} \approx I_P + 3.17\,U_P$$

Ionization potential

$U_P \propto I\lambda^2$

Quiver energy of e$^-$

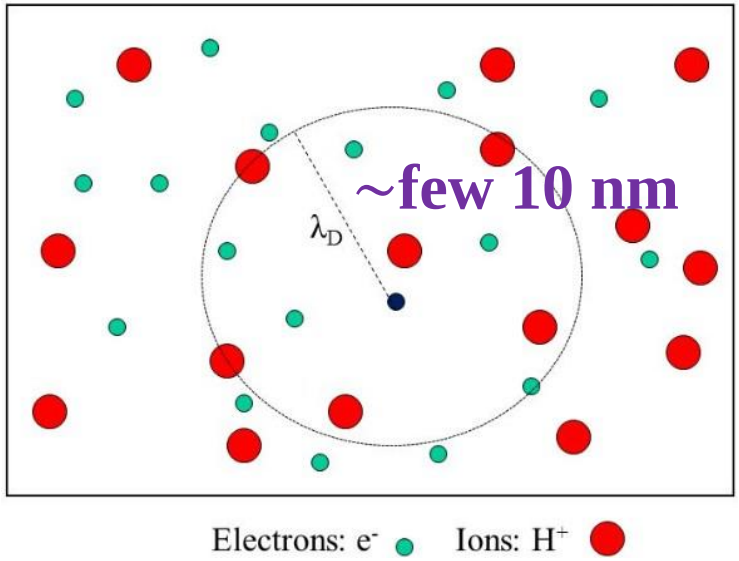
J. Zhou, J. Peatross, M. M. Murnane, H. C. Kapteyn, and I. P. Christov, PRL 76, 752 (1996)

What is Plasma ?

"Plasma is a quasi-neutral medium of charged and neutral particles that exhibits collective behavior". An ionized gas must satisfy the following three criteria to be called a plasma.

1) $n \lambda_D^3 >> 1$ (Shielding)
2) $L >> \lambda_D$ (Quasi-neutral)
3) $\omega_p \tau >> 1$ (Collective nature)

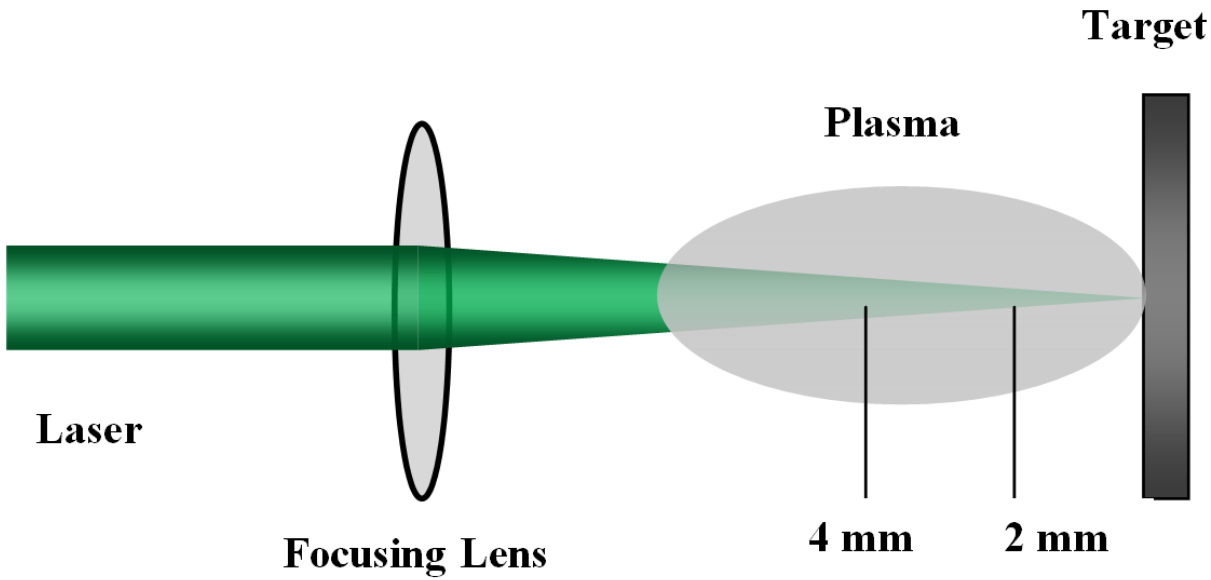
Debye length= Range of influence



Methods of Generation

- Arc discharge
- Glow discharge
- RF discharge
- Ohmic heating
- *Laser produced plasma*

Plasma production by using light (Lasers)



Plasma diagnostic methods

Radiation emitted from the plasma.

- **Black body radiation**
- **Bremsstrahlung radiation (Free-Free radiation)**
- **Recombination radiation (Free-Bound radiation)**
- **Line radiation (Bound-Bound radiation)**

Use of external radiation.

- **Laser scattering techniques (e.g., Thomson scattering)**
- **Interferometry**
- **Shadowgraphy**

Langmuir Probe studies.

Plasma Plume Imaging.

Methodology

PHASE 1

Generation,
Characterization
Optimization of plasma

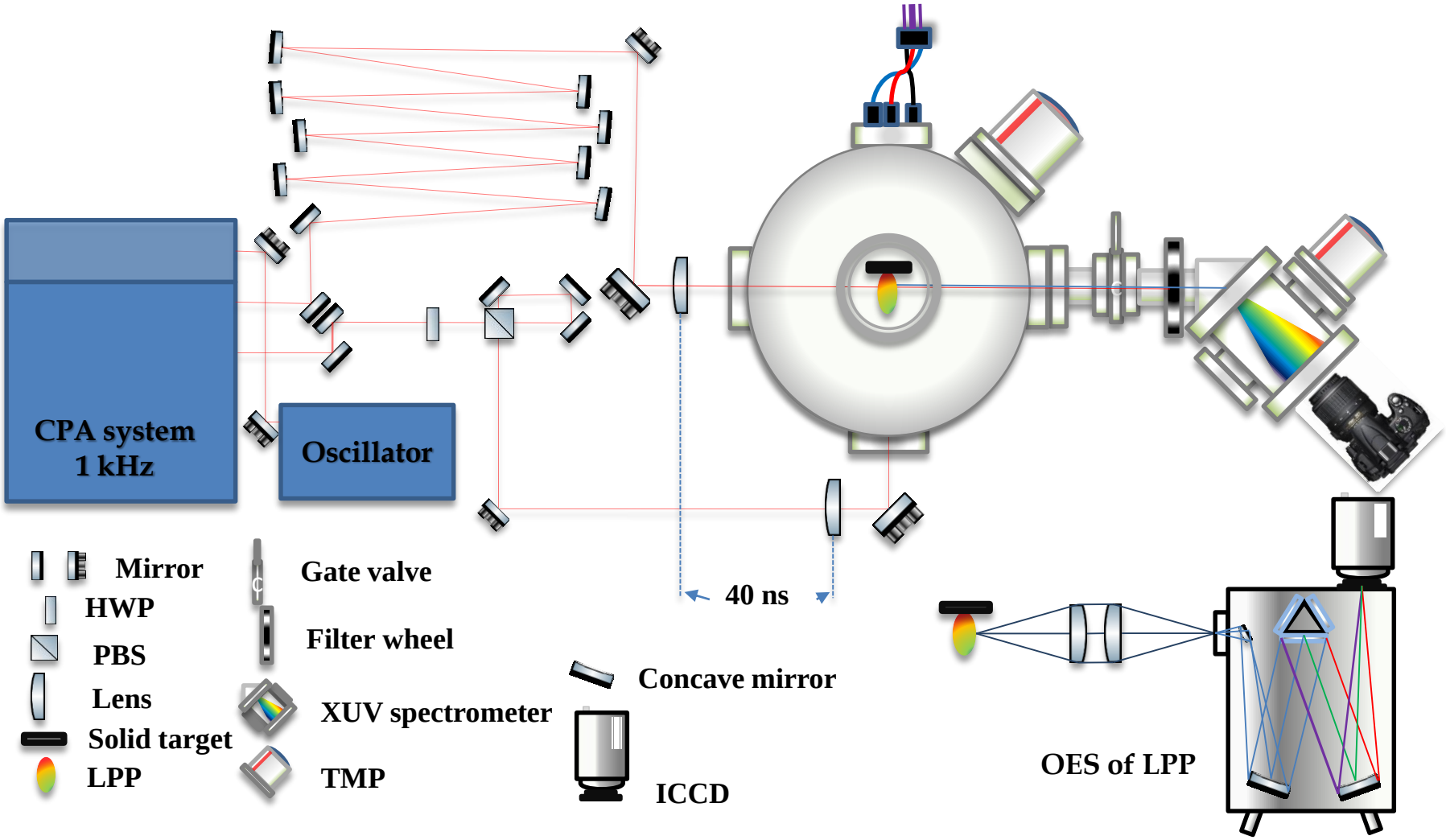
} Abundance of species
Position
Time

PHASE 2

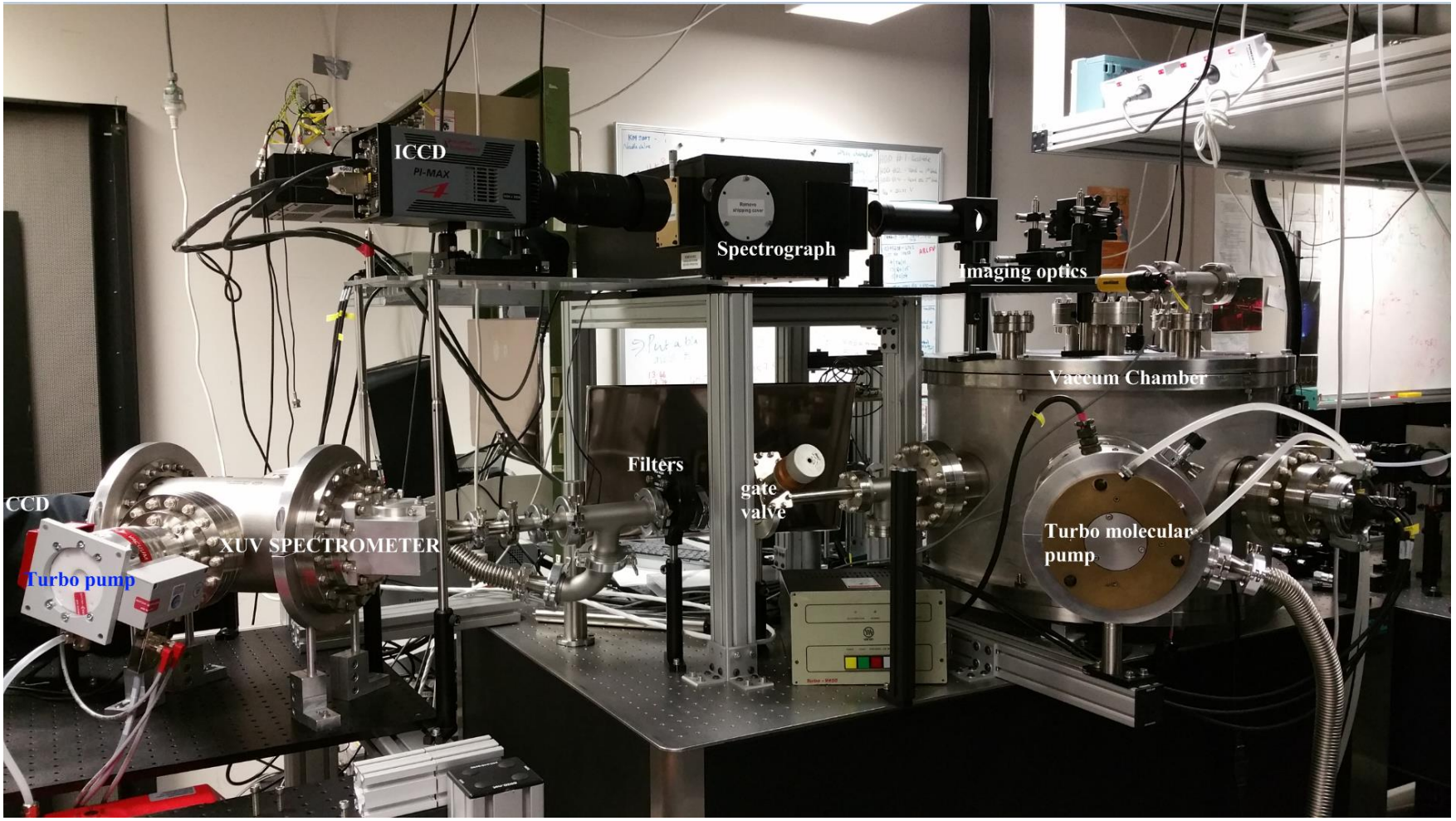
- Irradiate the plasma with driving pulse
- Use of various beams and material to attain the aim

} HHG
Increase the E_c
Improve the brightness

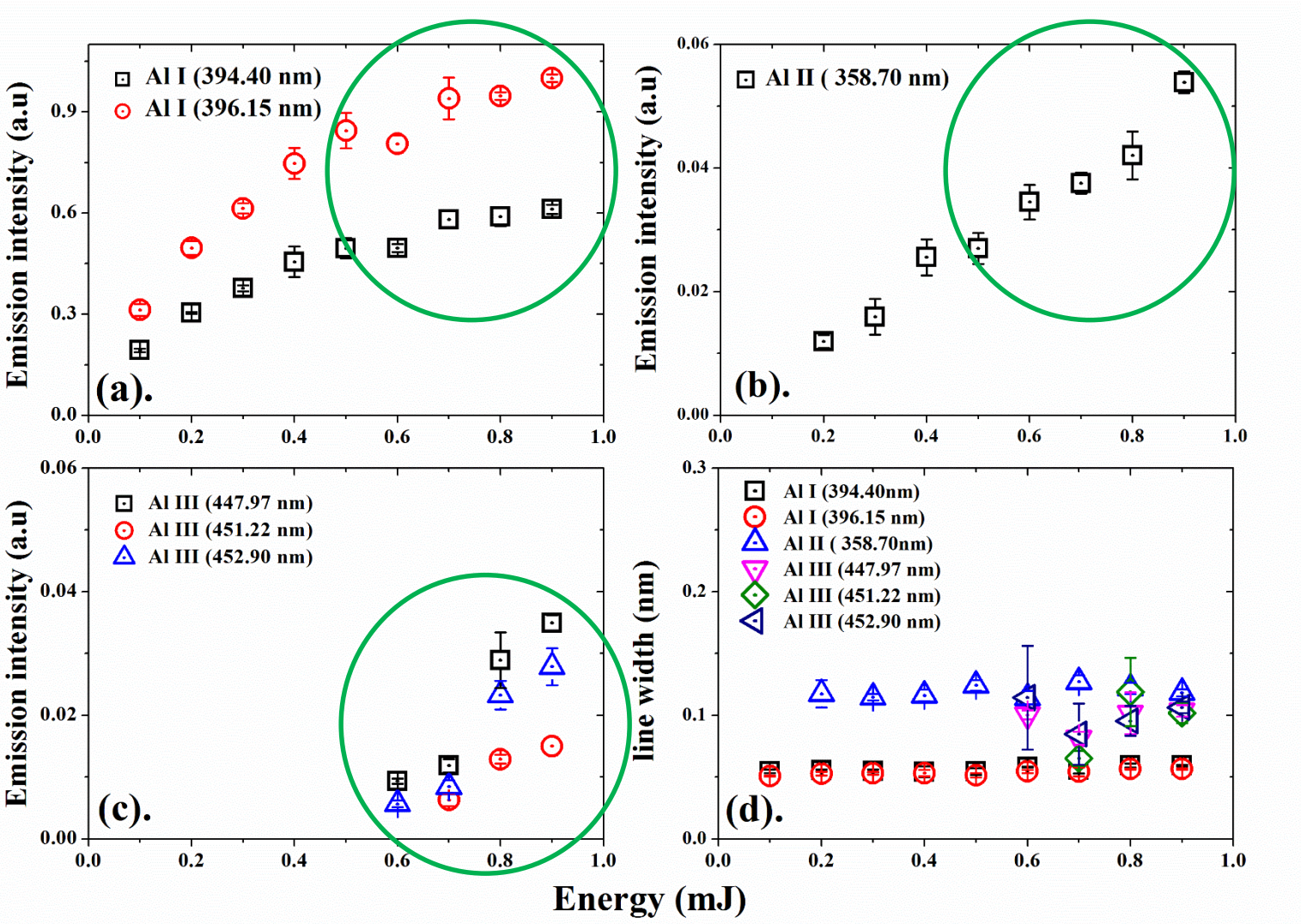
Experimental set up at Griffith



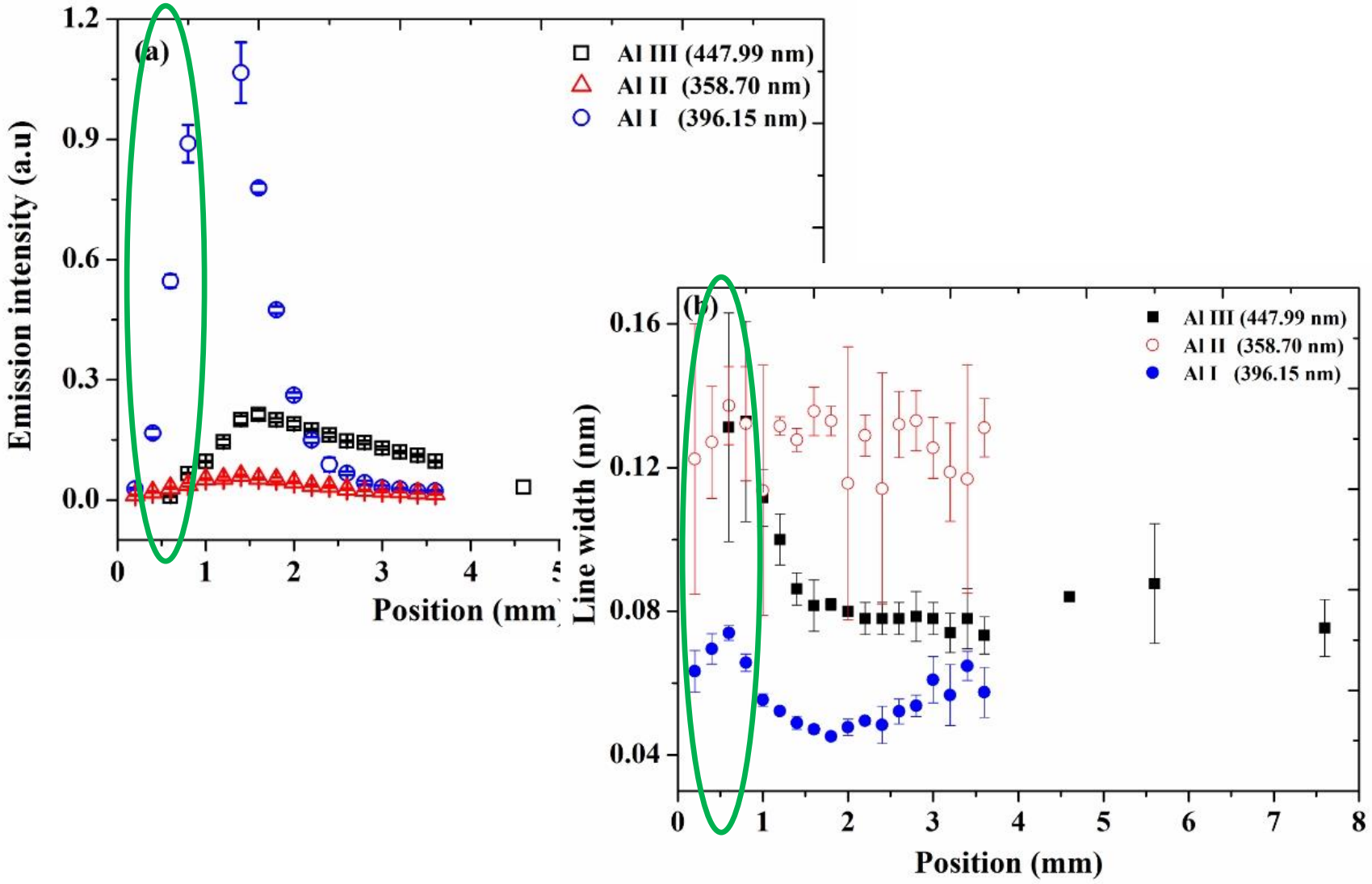
Experimental setup



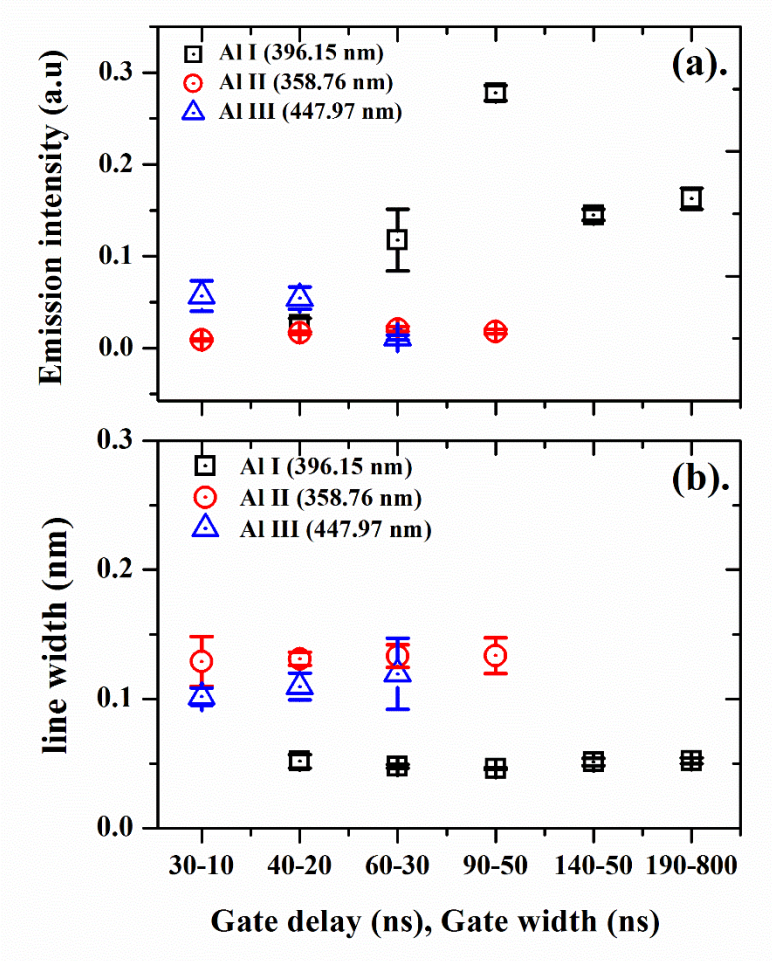
Energy variation (700 µm, 500 ns)



Position variation (0.9 mJ, 500 ns)



Gate delay/ gate width variation



PHASE 1

Generation,
Characterization
Optimization of plasma

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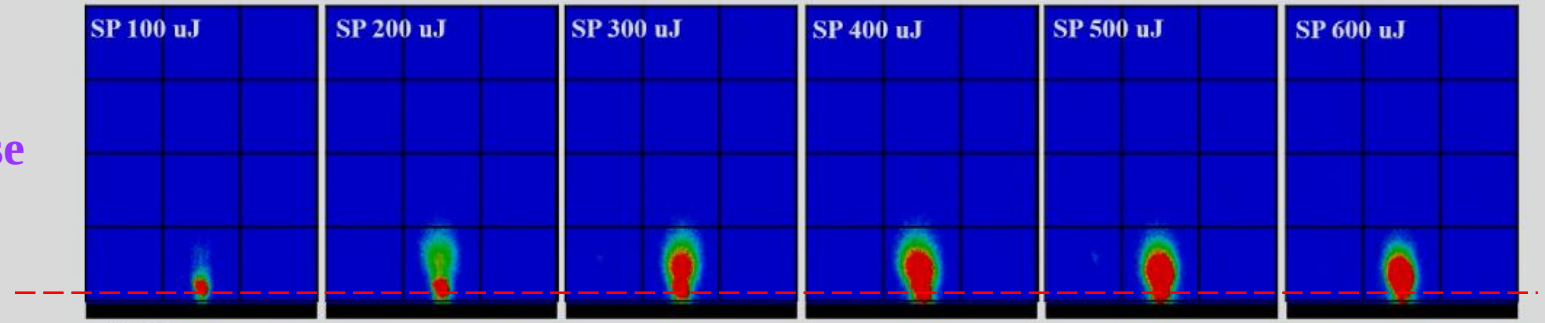
Abundance of species
Position
Time

(a). Emission intensity and (b). Stark width measured for 0.9 mJ irradiation energy recorded for various t_w and t_d.

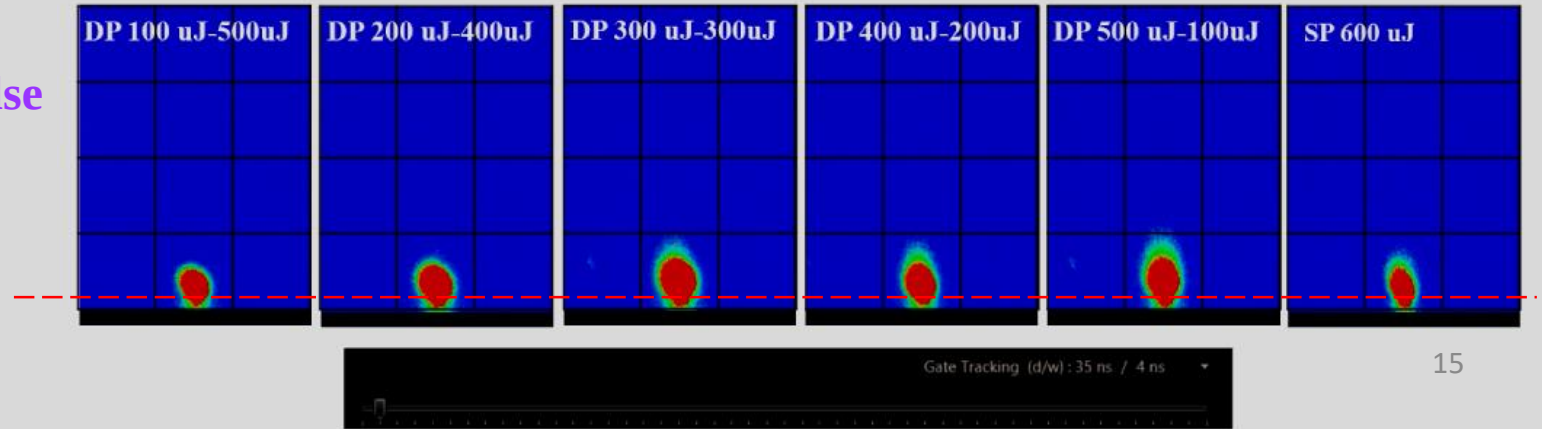
Hydrodynamics of LPP (ICCD imaging)

- **Time-gated imaging of the plasma help to map the spatial extent up to which the plasma expands in the time.**
- **To know the plasma dimensions and hydrodynamics on plume expansion.**

Single Pulse

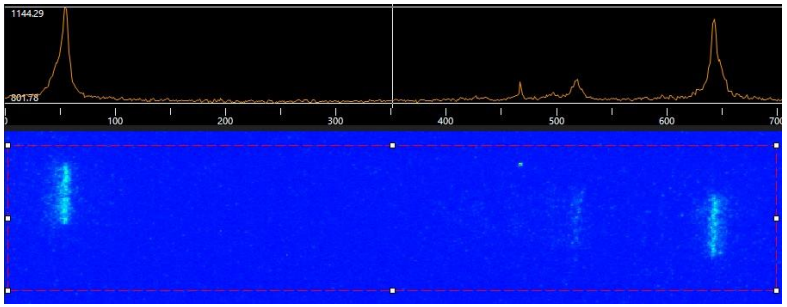


Double Pulse



Progress towards this project.

- The space and time at which the plasma can be irradiated with the femtosecond pulses to generate harmonics is optimized and ready to go for the second phase of the experiment.
- HHG trials has been conducted.



Conclusion

- **Spatio-temporal characterization of a picosecond laser produced aluminium plasma is carried out using the technique of optical emission spectroscopy and plume imaging.**
- **With an energy of 1 mJ, at a position ~ 1 mm close to the target surface, for a time between 40 ns to 60 ns, the emission from Al III maximizes.**
- **This fixes the desired space and time at which the plasma can be irradiated with the femtosecond pulses to generate harmonics, expecting an increased/improved cut-off if phase matching conditions are satisfied.**

Future Plans

1. HHG from neutral-rich plasma before proceeding to HHG from ionized species, and generate harmonics at optimized plasma conditions.
2. Vary the nature of plasma plume, for eg. an extended plasma or plasmas generated using different beam shapes, to improve the quasi-phase matching condition.
3. These plasmas would be investigated for their properties along with the harmonic generation.
4. Finally compare all these harmonics generated via different methods and then choose the best among them to attain the aim of the experiment.

Thank You